FIVE-YEAR GROWTH RESPONSE IN DRAINED AND FERTILIZED BLACK SPRUCE PEATLANDS.

II. STEM ANALYSIS

E. Sundström and J.K. Jeglum

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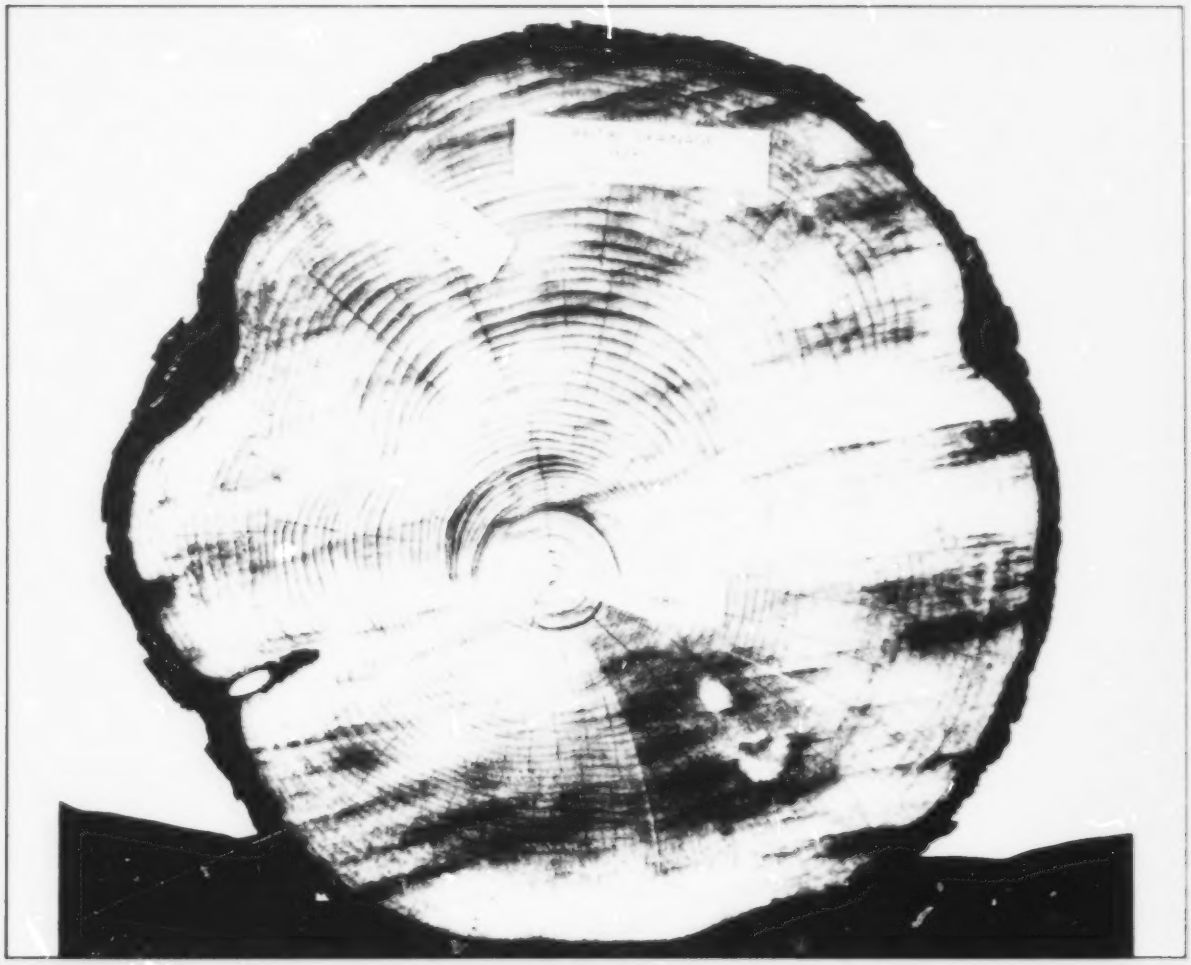

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FIVE-YEAR GROWTH RESPONSE IN DRAINED AND FERTILIZED BLACK SPRUCE PEATLANDS. II. STEM ANALYSIS

Erik Sundström[1]
and
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Ontario Region
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ABSTRACT

Stem analysis of 150 peatland black spruce (*Picea mariana* [Mill.] B.S.P.) trees in northeastern Ontario was used to examine the response of tree growth to drainage. Mean increments for 5 years before and 5 years after drainage did not provide any evidence of a response to drainage. However, results based on an analysis of each individual year's growth indicated a growth decline in trees on drained sites in the first 3 years after drainage. In the two following years, growth was higher for trees on drained than on undrained sites, especially in younger trees of medium size and with large crowns. Diameter growth of trees on drained sites was found to be greatest higher up in the stem.

RÉSUMÉ

Les effets du drainage sur la croissance des arbres ont été étudiés par analyse de la tige de 150 épinettes noires (*Picea mariana* [Mill.] B.S.P.) poussant dans des tourbières du nord-est de l'Ontario. Les accroissements moyens pour les cinq années précédant et les cinq années suivant le drainage n'indiquent aucun effet. Toutefois, les accroissements annuels font voir une diminution de la croissance sur les terrains drainés les trois premières années qui ont suivi le drainage. Au cours des deux années suivantes, la croissance a été plus élevée sur les terrains drainés que sur ceux qui ne l'étaient pas, surtout chez les arbres plus jeunes, de grosseur moyenne et à large houppier. Chez les arbres des terrains drainés, l'accroissement du diamètre était supérieur dans la partie plus haute de la tige.

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INTRODUCTION

A number of studies, particularly from the Fenno–Scandinavian countries (Malmström 1928; Heikurainen 1961, 1964, 1966; Hånell 1984), have reported improved forest growth following drainage. It has been shown that tree size was of crucial importance in determining the response to drainage; small- and especially medium-sized trees respond best to drainage, and larger trees do not respond as well. Tree age also has some influence on drainage response; old trees do not respond as well as younger ones. Other factors that influence the response are the tree's vigor and the size of its crown.

It normally takes from 3 to 7 years for trees in the Fenno-Scandinavian countries to adjust and respond to the new conditions created by lowering the water table and increasing aeration of the soil. The length of time for growth of annual rings to stabilize at a new level of periodic increment is only 3 or 4 years for Scots pine (*Pinus sylvestris* L.), whereas Norway spruce (*Picea abies* [L.] Karst.) requires 6 to 7 years (Seppälä 1969).

Payandeh (1973) reported that the growth response of individual black spruce (*Picea mariana* [Mill.] B.S.P.) trees to drainage was more pronounced than that of stands. Younger trees with large crowns growing on better sites showed the best responses. Annual diameter growth in one tree had tripled 40 years after drainage and annual height growth had improved 3.5-fold during the same period. In another drainage experiment, Stanek (1968) studied the growth responses of 11 young black spruce saplings. He found that both annual diameter and annual height growth had increased five-fold 5 years after drainage compared with the same parameters 5 years before drainage. Older trees with short and narrow crowns and trees that were already growing well showed little response to drainage.

A study of 5-year growth response to drainage in permanent growth plots at the Wally Creek Drainage Area in northern Ontario has recently been completed (Sundström 1992). In this study, annual diameter increments were 80% higher than those of the control 5 years after drainage in plots that were both drained and fertilized. Plots close to a drainage ditch and that had not been fertilized also had 80% higher diameter growth. On the poorest site (classified as OG14 according to the Forest Ecosystem Classification for the Clay Belt [Jones et al. 1983]), drainage alone increased diameter growth by 90%, and with both drainage and fertilization, the diameter increment almost tripled over that on untreated plots. On better sites (OG8 and OG12), no growth response to drainage was found.

The information collected from the Wally Creek study permanent growth plots (Sundström 1992) did not permit a detailed examination of when and in which trees the response to drainage occurred. To clarify this matter, a destructive sample of the trees was taken so that a stem analysis could be performed; the results form the basis for the present report. The objectives of this study were to determine: (1) when the drainage response occurred; (2) the influence of tree age, size and crown size on the response; and (3) whether the growth response was different at different heights on the stem.

MATERIALS AND METHODS

The Study Area

The study area (49°03'N, 80°40'W) is located 30 km east of Cochrane, Ontario, in the Northern Clay Section of the Boreal Forest Region (Rowe 1972). It is dominated by black spruce forest, most of which was harvested in 1930 by means of horse skidding. This operation left much advanced growth, and today there is an uneven-aged forest over most of the area, with trees ranging from 50 to 250 years in age. About 300 ha of forested area was systematically drained in 1984 with 70 km of ditches; the predominant ditch spacing was 40 m. For more information about the study area, see Jeglum (1991) and Sundström (1992).

Destructive sampling of trees was performed at two locations, one in a drained area with ditch spacings of 42, 19 and 42 m, the other in an undrained control on the opposite side of the highway (Fig. 1). Both sites were classified as OG11 using the guidelines of the Forest Ecosystem Classification for the Clay Belt (Jones et al. 1983).

Sampling and Measurements

Destructive sampling of 150 trees with DBH >5 cm was done in June 1990. Half of the trees were collected in the drained area and half from an undrained site, referred to henceforth as the control. Trees (25) were sampled in each of three size classes based on height: small (<8 m), medium (8 to 11 m) and tall (≥11 m). In the drained area, trees were sampled at different distances (from 0.1 to 19 m) from the ditch.

Discs were cut from each tree at intervals of 15 cm up to breast height (in this case, 135 cm) and thereafter, every 100 cm. For each tree, a 2-m top was collected separately, and crown radius (the length of the longest branch) and length (from the top to the lowest living branch) were recorded. For ease of comparison, crown lengths were transformed to relative crown lengths (i.e.,

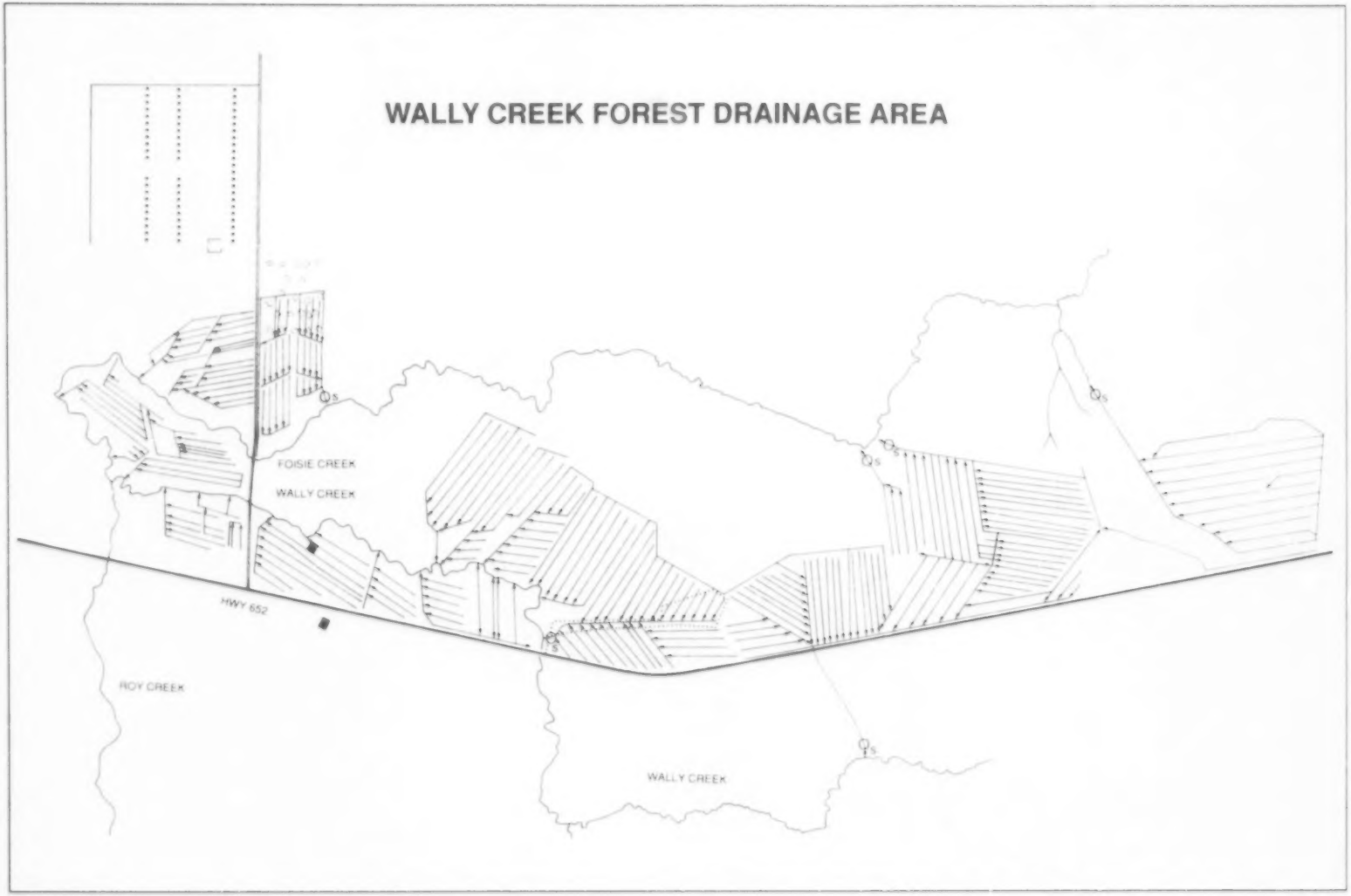


Figure 1. The drainage area and the location of the two plots (■) used for destructive sampling.

actual crown length divided by the length of the tree, expressed as a percentage).

Each disc was measured and analyzed with a computerized tree-ring increment measurement (TRIM) system and its accompanying analysis program (Fayle and MacIver 1986, Miller 1991). This provided the diameter increment and the mean width of each annual ring at different heights along the stem. The widths of the pith and bark, as well as age and height (including the 2-m top), were also recorded with the system. Annual height increments for the previous 10 years were measured using the 2-m tops.

RESULTS

In the year before drainage (1984), sampled trees in the drained area were, on average, younger and somewhat smaller in diameter, height and crown radius than trees from the control area (Table 1). Stocking was higher in the drained area, with 3,600 trees/ha versus 2,800 trees/ha in the control. The relative crown length was similar in both groups.

Diameter and Height Increments

Mean annual diameter increment at breast height for the 5 years before drainage was between 0.7 and 0.8 mm/year in both groups of trees (Fig. 2, Table 2). For the 5 years following drainage, the annual diameter increment had increased to about 1.1 mm/year in both drained and control groups. The mean diameter increment was slightly but not significantly ($P<0.05$) higher in trees on the drained site both before and after drainage.

Mean height increment was between 8 and 9 cm/year in both groups before drainage (Fig. 2, Table 2). For the 5 years after drainage, it was about 11 cm/year in both groups.

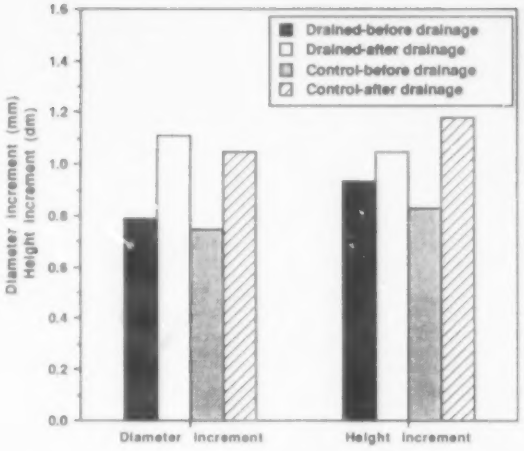


Figure 2. Mean annual diameter and height increments for the 5-year periods before and after drainage in trees from drained and control sites.

Annual diameter (DBH) increment for each of the last 10 years showed a similar pattern for trees on both drained and undrained sites, except for the last 2 years (1988 and 1989); then, the growth curves diverged and trees on drained sites had a higher mean diameter increment (Fig. 3).

Trees in the drained area had slightly higher mean height increments each year before and 1 year after drainage than trees from the control area, a relationship that reversed after drainage (Fig. 4). The differences were usually between 1 and 2 cm, but were nonsignificant ($P<0.05$).

Tree Size and Increments

For both drained and control sites, tall trees (>11 m) had greater annual diameter increments than medium or small trees (Fig. 5). Tall trees grew better in the drained

Table 1. Summary data for the sample trees at the start of the study in the fall of 1984 (70 trees from drained and 72 from control sites). Crown-size values are from 1989.

	Drained			Control		
Variable	Mean	Range	S.D.[a]	Mean	Range	S.D.[a]
Age (years)	73	48–169	23.1	108	55–243	34.6
Diameter (DBH, cm)	9.4	3.6–16.1	2.6	10.1	4.7–16.8	2.8
Height (m)	8.8	4.1–14.0	2.7	9.3	4.8–14.8	2.8
Volume (m^3)	0.035	–	0.003	0.044	–	0.004
Crown radius (m)	1.7	1.0–3.2	0.5	2.3	1.0–4.3	0.7
Relative crown length (%)[b]	57	26–81	13	57	29–93	12

[a] standard deviation
[b] relative crown length = length of crown divided by total height of tree.

Table 2. Annual diameter and height increments 5 years before and 5 years after drainage for trees in drained and control areas.

	Drained site			Control site		
	Mean	Range	S.D.[a]	Mean	Range	S.D.[a]
Before drainage						
DBH increment (mm/year)	0.79	0.12–1.98	0.48	0.75	0.20–1.71	0.38
Height increment (mm/year)	93	23–177	38.3	83	13–147	28.1
After drainage						
DBH increment (mm/year)	1.11	0.13–2.61	0.61	1.05	0.20–2.30	0.44
Height increment (mm/year)	114	26–262	26.2	118	48–211	38.1

[a] standard deviation

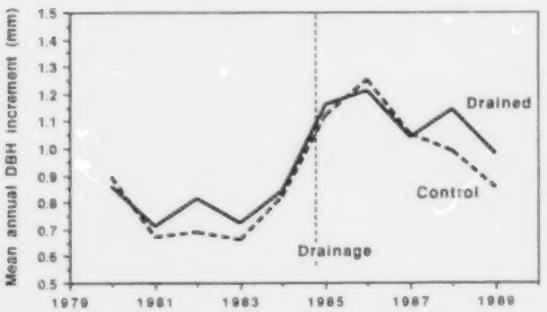


Figure 3. Mean annual diameter (DBH) increments before and after drainage for trees from drained and control sites.

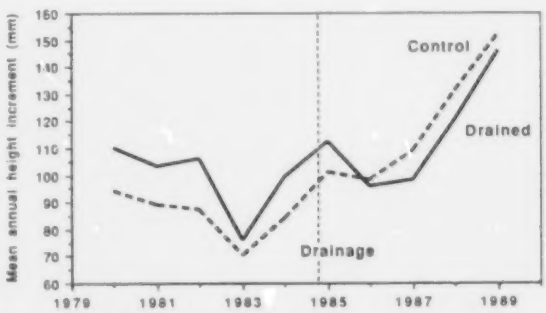


Figure 4. Mean annual height increments before and after drainage for trees from drained and control sites.

area whereas short trees grew better in the control area both before and after drainage.

During the first 3 years after drainage, diameter increment for trees on drained and control sites remained similar for tall and medium trees (Fig. 5). However, in the fourth and fifth growing seasons after drainage (1988 and 1989), tall and medium trees in the drained area exhibited greater diameter growth than those in the control. Short trees responded differently: their growth increment decreased in the second and third years after drainage (1986 and 1987) and then recovered and paralleled the control in 1988 and 1989.

Annual height increments decreased in medium and short trees in the drained area in the second year after drainage (1986), a decline that did not occur to the same extent in trees in the control (Fig. 6). In tall trees, the height increments in drained and control areas showed the same trends both before and after drainage.

Age and Increments

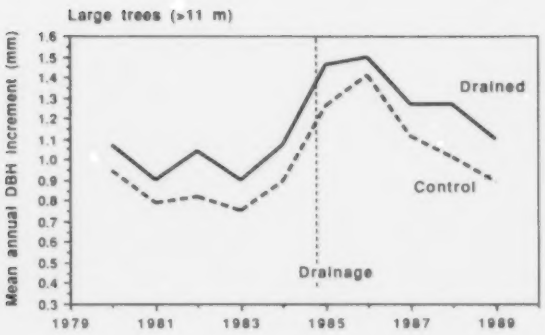
Trees between 85 and 100 years of age had the best annual diameter growth, whereas trees older than 100 years had the lowest (Fig. 7). This trend held for both drained and control areas.

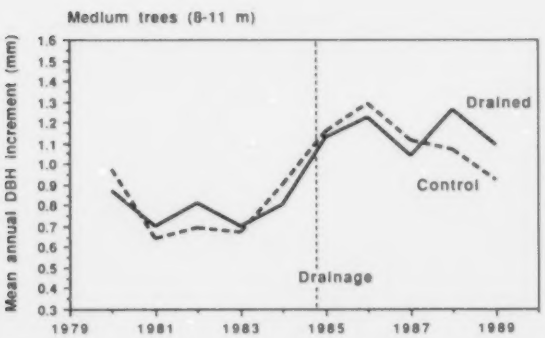
Four years after drainage (1988), young (<70 yrs) trees in the drained area showed an increase in diameter increment that was slightly higher than that for trees in the control (Fig. 7). The same was true for young to middle-aged (71 to 85 years) trees 1 year later, in 1989. In 1987, there was a general decline in diameter increments, which continued to fall in the control, but which increased in 1988 in trees in the drained area.

In the first 2 or 3 years after drainage, there was a decline in height increment in trees of all age classes in the drained area; this did not occur in the control (Fig. 8). The decline in height increment was especially pronounced in trees between 71 and 85 years of age.

Crown Radius and Increments

Trees with wider (>2 m) crowns had the best diameter growth in both drained and control areas, both before and after drainage (Fig. 9). Trees with the narrowest crowns (<1.5 m) had the poorest diameter growth, especially in the drained area. Trees with the





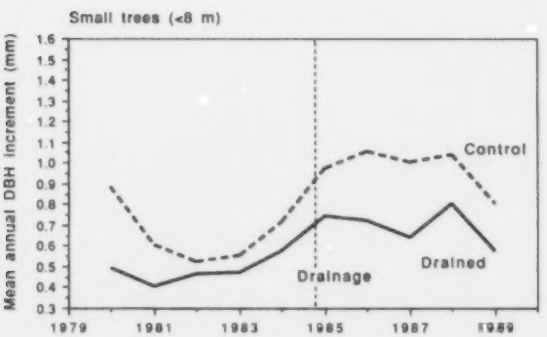
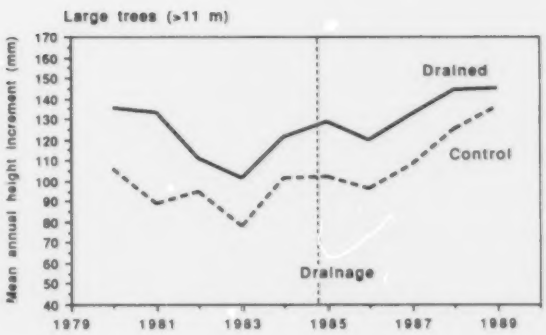
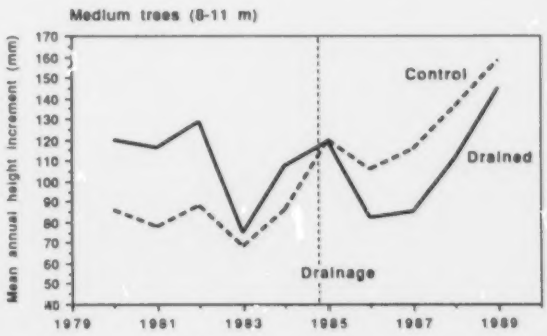


Figure 5. Mean annual diameter (DBH) increments before and after drainage for trees in three size classes (<8, 8–11 and >11 m) from drained and control sites.





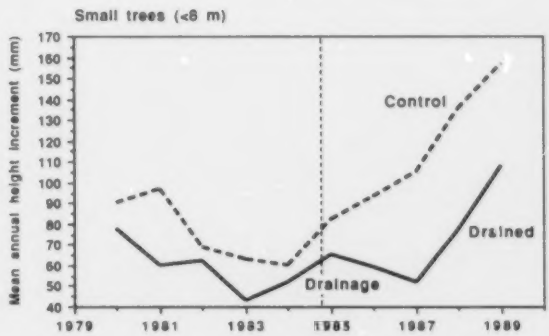


Figure 6. Mean annual height increments before and after drainage for trees of three size classes (<8, 8–11 and >11 m) from drained and control sites.

widest crowns (>2.5 m) in the drained area increased their diameter growth more in 1988 than trees with the same crown width in the control.

In general, trees with wider crowns had the best height increments, and this was especially pronounced in the drained area both before and after drainage (Fig. 10). In 1986, the second year after drainage, height increments decreased more sharply in trees in the drained area than in controls, especially for trees with narrow crowns.

Crown Length and Increments

Trees with long (>70% of the tree height) crowns had the best diameter and height increments before and after drainage, especially in the drained area (Fig. 11, 12). Again, in 1988 there was an increase in diameter growth in trees in the drained area that was not found in trees in the control area (Fig. 11). Trees with shorter (<56% of the tree height) crowns had the lowest increments before and after drainage, in both drained and control areas (Fig. 12).

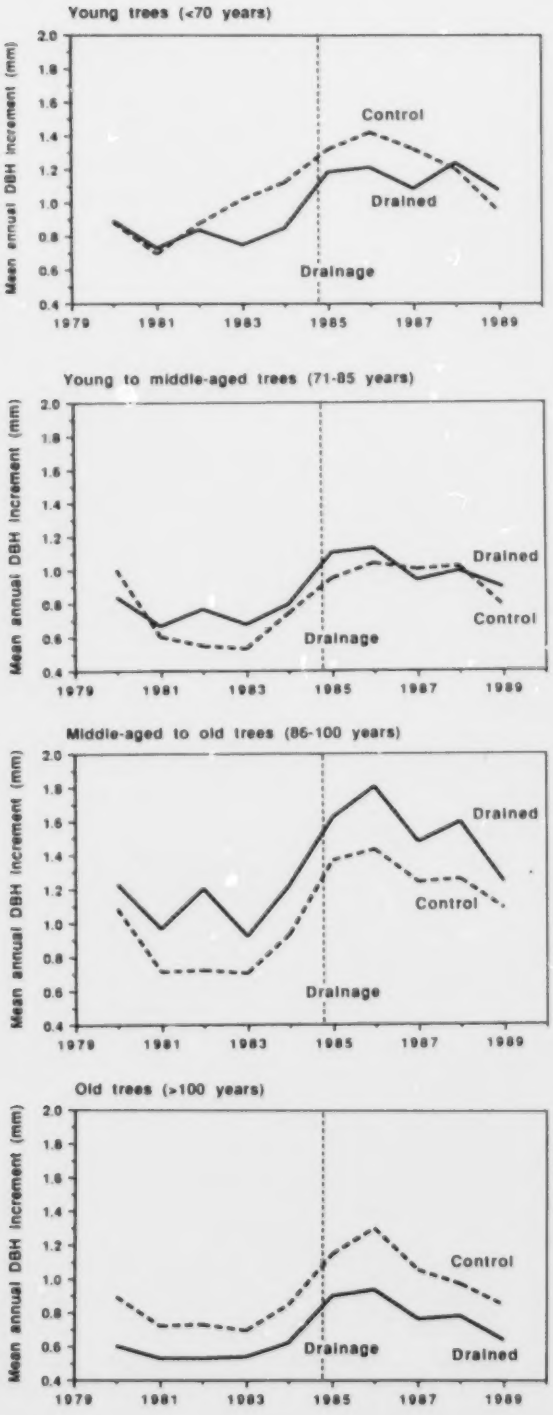


Figure 7. Mean annual diameter (DBH) increments before and after drainage for trees in four age classes (<70, 71–85, 86–100 and >100 years) from drained and control sites.

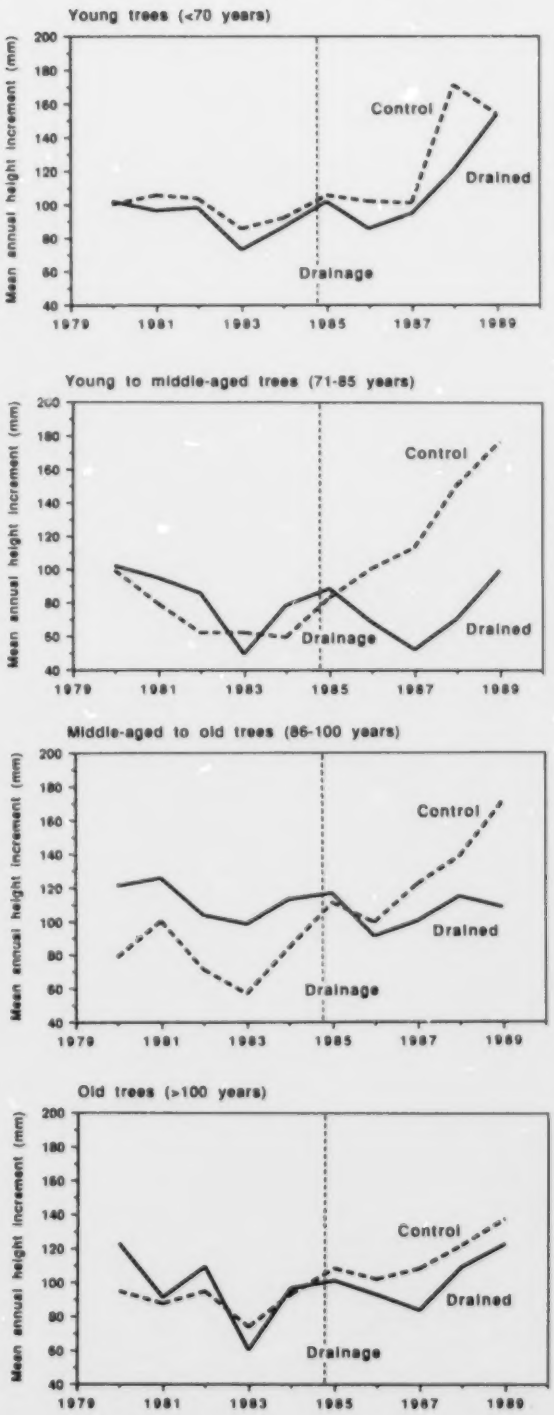


Figure 8. Mean annual height increments before and after drainage for trees in four age classes (<70, 71–85, 86–100 and >100 years) from drained and control sites.

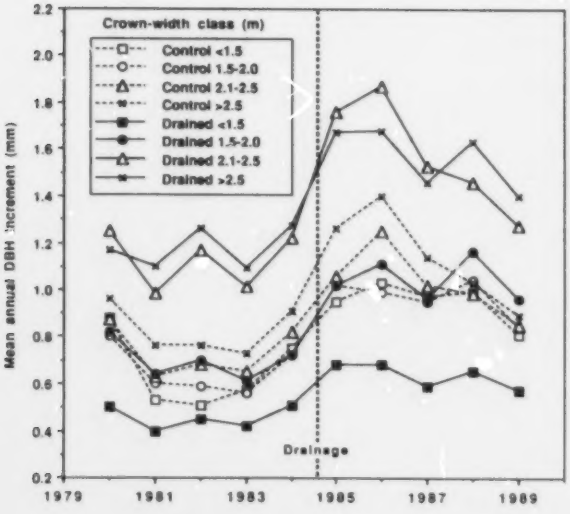


Figure 9. Mean annual diameter (DBH) increments before and after drainage for trees in four crown-width classes (<1.5, 1.5–2.0, 2.1–2.5 and >2.5 m) from drained and control sites.

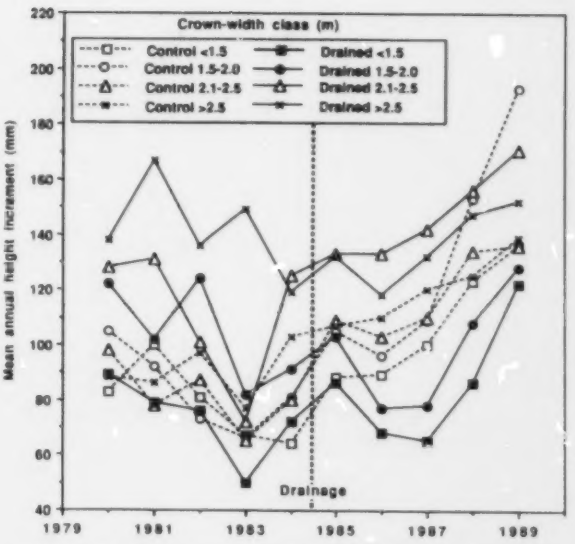


Figure 10. Mean annual height increments before and after drainage for trees in four crown-width classes (<1.5, 1.5–2.0, 2.1–2.5 and >2.5 m) from drained and control sites.

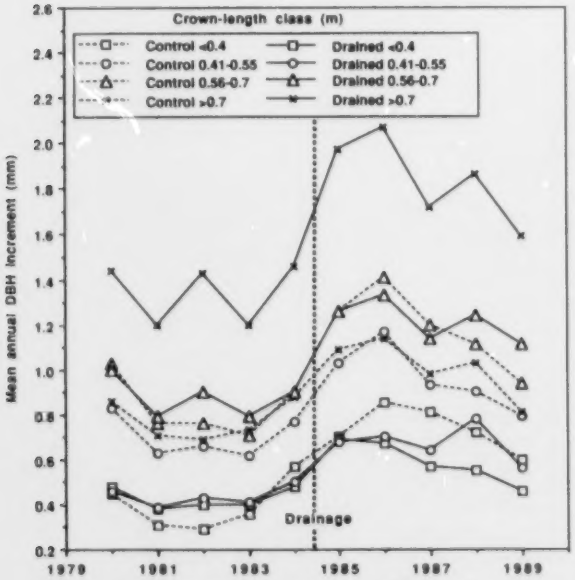


Figure 11. Mean annual diameter (DBH) increments before and after drainage for trees in four relative-crown-length classes (<0.4, 0.41–0.55, 0.56–0.7 and >0.7) from drained and control sites. (Relative crown length = crown length/tree height.)

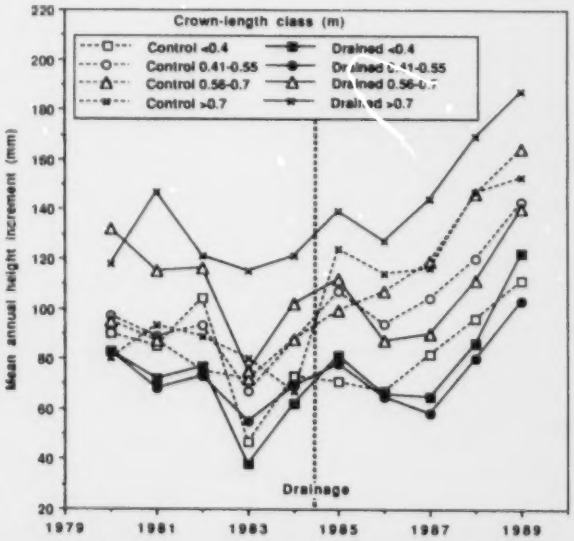


Figure 12. Mean annual height increments before and after drainage for trees in four relative-crown-length classes (<0.4, 0.41–0.55, 0.56–0.7 and >0.7) from drained and control sites. (Relative crown length = crown length/tree height.)

Distance to Ditch and Increments

There was a general increase in diameter growth 2 years after drainage (1986) and a decrease in the third year (1987) (Fig. 13). Trees closer to a ditch had generally lower increments both before and after drainage. In the fourth year after drainage (1988), trees of all size classes on drained sites showed an increase in diameter growth that was not found in the control. This increase in diameter growth was most pronounced in medium-sized trees within 3 m of a ditch (Fig. 14).

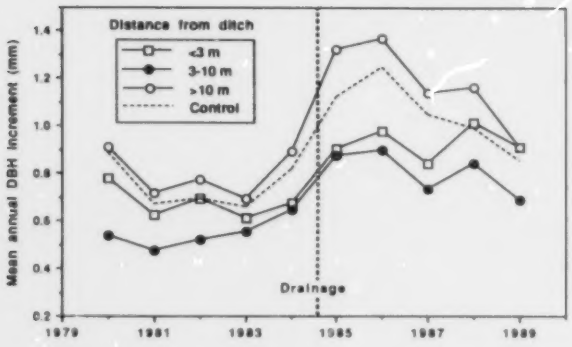


Figure 13. Mean annual diameter (DBH) increments before and after drainage for trees on drained sites at three distances from a ditch (<3, 3–10 and >10 m) and for trees from a control site.

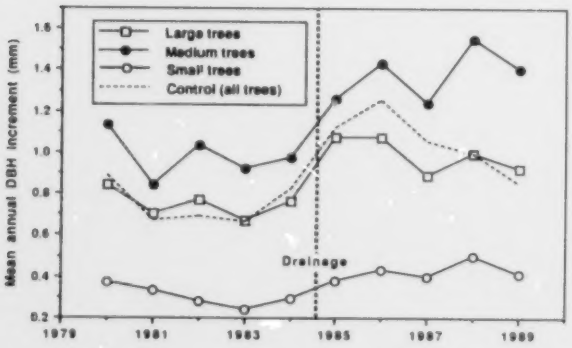


Figure 14. Mean annual diameter (DBH) increments before and after drainage for trees in three size classes (<8, 8–11 and >11 m) within 3 m of a ditch on drained sites and for all trees from a control site.

In contrast with the increase in diameter increments, height increments dropped sharply 2 years after drainage (1986) in drained trees at all distances from a ditch (Fig. 15). The most pronounced drop was for trees closest to a ditch (<3 m), whereas the smallest drop was for trees in the control and >10 m from a ditch. In 1988 and continuing into 1989, height increments increased in drained as well as control areas. Both the greatest decrease in 1986 and the greatest increase in 1988 in height increments were found in medium-sized trees close to a ditch (Fig. 15, 16).

Diameter Increments at Different Heights on the Stem

Annual diameter increments were greatest above breast height in trees of all size classes, and on both drained and control sites (Fig. 17–19). Tall trees, for example, had annual diameter increments of about 0.8 to

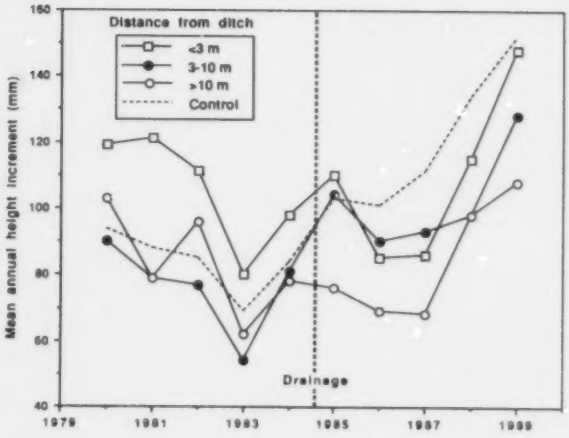


Figure 15. Mean annual height increments before and after drainage for trees on drained sites at three distances from a ditch (<3, 3–10 and >10 m) and for trees from a control site.

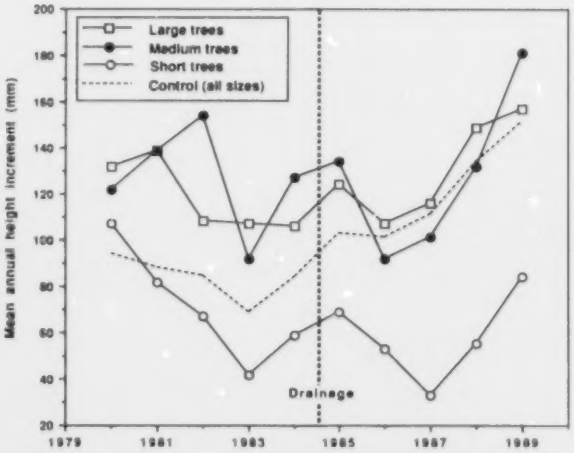


Figure 16. Mean annual height increments before and after drainage for trees in three size classes (<8, 8–11 and >11 m) within 3 m of a ditch on drained sites and for all trees from a control site.

1.5 mm at breast height, compared with 1.4-to 2.6-mm increments 2 m below the top (Fig. 19). Diameter growth decreased at all heights in trees on drained sites during the second and third years after drainage (1986 and 1987), especially in short or tall trees (Fig. 17 and 19).

In 1988, annual diameter growth increased for all sizes of trees on drained sites at most heights on the stem. The increases were most pronounced higher up for tall and medium trees, but lower down in small trees (Fig. 17–19). In comparison, the control trees showed no changes, or relatively small increases or decreases.

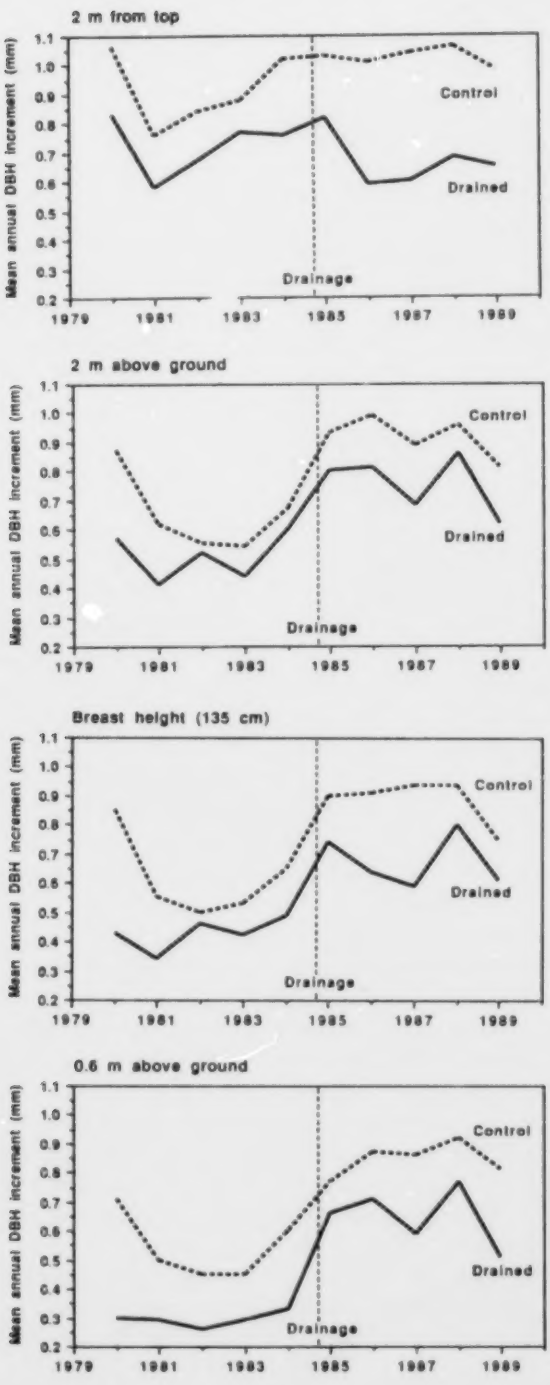


Figure 17. Mean annual diameter increments before and after drainage at four different heights in the stem (at 2 m from the top, and at 2, 1.35 and 0.6 m above ground) for short (<8 m) trees from drained and control sites.

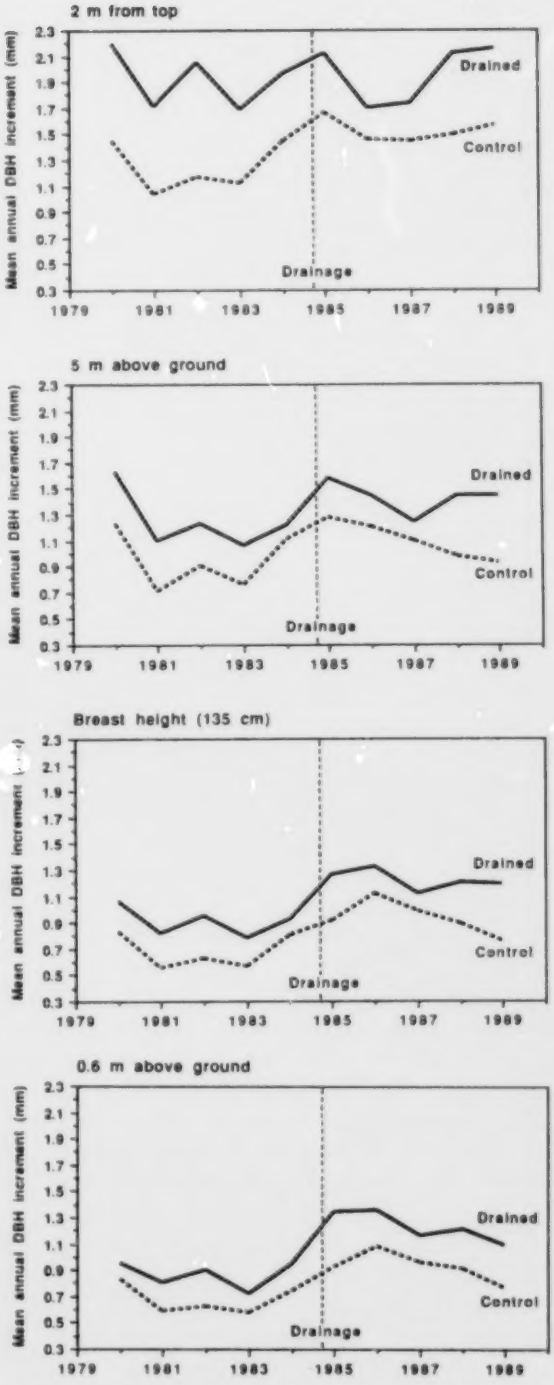


Figure 18. Mean annual diameter increments before and after drainage at four different heights in the stem (at 2 m from the top, and at 5, 1.35 and 0.6 m above ground) for medium-sized (8–11 m) trees from drained and control sites.

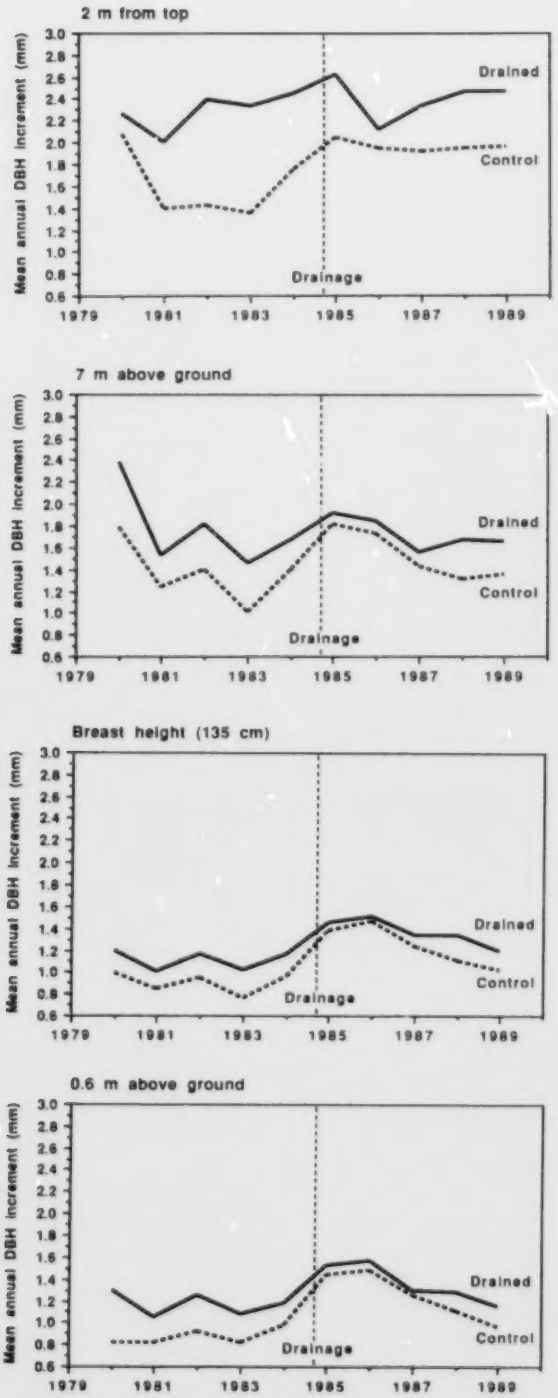


Figure 19. Mean annual diameter increments before and after drainage at four different heights in the stem (at 2 m from the top and at 7, 1.35 and 0.6 m above ground) for tall (>11 m) trees from drained and control sites.

Stepwise Linear Regressions

Mean annual diameter and height growth for the 5 years before and the 5 years after drainage, on both drained and control sites, were regressed as functions of height, age, crown size (radius and length) and distance to ditch (Table 3). Diameter growth, both before and after drainage, was positively correlated with crown size (especially crown length) and negatively correlated with age, indicating that younger trees with large crowns had the best diameter growth, independent of drainage.

Height growth in control trees before drainage was positively correlated with height; in the drained area, growth was positively correlated with crown length but negatively correlated with crown radius (Table 3). This indicates that tall trees in the control and trees with long but narrow crowns in the drained area had the best height increments before drainage. Height growth after drainage was positively correlated with crown length in trees in both drained and control areas and negatively correlated with age for trees in the drained area; this is an indication that older trees had lower height growth after drainage (Table 3).

The regression equations for trees in the drained area accounted for about 50% of the variation, whereas the equations had much lower R^2 values for the controls, an indication that variables other than those tested explain the majority of the variation in increment in undrained areas (Table 3).

DISCUSSION

Five years after drainage, the mean annual diameter growth of trees on the drained site increased by 40% compared with that for the 5 years before drainage. However, trees in the undrained control area showed the same growth increment during this period. It is obvious that the increased mean annual increment found after drainage was not a drainage response, but more likely reflects variation in the climate, temperature and precipitation, since it was found in both drained and control treatments. Many drainage studies, however, only reported data on increments before and after drainage in trees on a drained site, and lacked growth information about trees in a comparable undrained control area. Neither Stanek (1968) nor Payandeh (1973) compared the increment they found in trees at the drained sites with trees located in an undrained control.

There was a decline in growth during the first 2 to 3 years after drainage, especially in height increments. This probably represents a period during which trees are adjusting to the new edaphic conditions. Four years after

Table 3. Summary of stepwise linear regressions for diameter and height growth before and after drainage as functions of size, age, crown size (length and radius), relative crown length and distance to ditch.

Response	Regression equation[a]	R^2	F
Diameter increment 5 years before drainage			
Drained area	Y = 0.0186 + 0.0117 CL + 0.0263 CR – 0.0007 A	0.50	20.34
Control area	Y = 0.0568 + 0.0063 CL + 0.0159 CR – 0.0005 A	0.22	6.02
Diameter increment 5 years after drainage			
Drained area	Y = –0.0152 + 0.2276 RCL + 0.0417 CR – 0.0006 A	0.55	24.49
Control area	Y = 0.0891 + 0.0102 CL – 0.0003 A	0.14	5.23
Height increment 5 years before drainage			
Drained area	Y = 39.93 + 15.76 CL – 17.68 CR	0.54	29.79
Control area	Y = 45.19 + 3.85 H	0.12	8.38
Height increment 5 years after drainage			
Drained area	Y = 70.58 + 13.41 CL – 0.45 A	0.42	18.20
Control area	Y = 69.30 + 95.16 RCL	0.09	5.95

[a] Abbreviations: A = age, CL = crown length, CR = crown radius, H= height, RCL = relative crown length, Y = diameter or height

drainage (1988), diameter growth increased more in the drained area than in the control, which could be an indication of the start of a drainage response. However, this increased growth was not significantly different from the growth of the control; this indicates a need for further stem analysis to determine if the differences persist and become significant in the future.

The increase in diameter growth occurred mostly in trees that were young to middle-aged and those that were short to medium-sized with large crowns, similar to what Stanek (1968) and Payandeh (1973) reported. The increase in growth in 1988 was also most pronounced in trees close to a ditch; this is the opposite of what Payandeh found, but was similar to the results reported from the Wally Creek permanent growth plot study (Sundström 1992). The results also indicated that diameter increment was larger higher up in the tree; if this is true, it means that trees on drained sites allocate more volume growth higher up in the stem, an observation that might be missed in studies in which volumes were calculated only from diameter measurements taken at breast height.

There are several possible explanations for the absence of a significant drainage response in this study. First, the single site chosen to represent the drained condition may not have been limited by excess water, and hence drainage might not have improved growing conditions significantly. This explanation is supported by the results based on 5 years of diameter growth after drainage (Sundström 1992); in this study, there was a large variation in the growth response between different plots. Some plots showed no growth responses to drainage (or very small responses), and the drained site in the present study may have been an area with a low potential drainage response. Unfortunately, data from the Sundström (1992) study were not available when a drained site was being chosen for the present study.

Another reason for the lack of a drainage response could be that 5 years is too short a time for a drainage response to occur in northern Ontario. It has been shown in Sweden that Norway spruce on wetlands with low production potentials require at least 5 to 7 years before they exhibit an increase in growth in response to drainage (Hånell 1984). In Alberta peatlands, black spruce did not respond for 3 to 6 years after drainage (Dang and Lieffers 1989). After that period, the net increase in tree ring growth increased nearly linearly until reaching a maximum at 13 to 19 years.

The drained area in the present study was also a disturbed site; it was located at the end of an old, temporary railway spur that could have compacted the peat on the site. Another important factor that may have influenced the growth response was the difference in stocking between the drained and control sites. Higher stocking on the drained site may have caused between-tree competition that reduced the growth response to drainage.

It is important to remember that when presenting annual increments as 5-year means, the yearly variation in growth is obscured. By comparing the actual annual increments in each year for trees in drained and control areas, the drainage response is more obvious. The results from this study indicate a difference in annual growth

patterns after drainage between drained and control areas, something that was not apparent from the 5-year mean increments.

CONCLUSIONS

1) When mean values for 5-year growth were compared before and after drainage, no drainage response could be seen in trees on the drained site compared with those on the control site.
2) An examination of the growth in each individual year provided some indication of a possible drainage response beginning in 1988, the fourth growing season after drainage.
3) The increased growth in 1988 was especially pronounced in trees that were young to middle-aged, tall or medium-sized, that had large crowns, and that were close to drainage ditches.
4) Stem analysis indicated an allocation of volume growth higher up in the stem in trees on drained sites, something that might not have been observed using only measurements taken at breast height.

RECOMMENDATIONS

A follow-up study should be carried out to determine whether these indications of increased growth in trees on drained sites are an effect of drainage or just random variation. The study should be made in 1995, 10 years after drainage, which should provide enough time for a drainage response to become established.

Instead of a costly and time-consuming destructive sampling, increment cores should be taken from the existing plots for destructive sampling in both drained and control areas, and, if possible, from fertilized plots in the Wally Creek study as well. Increment cores should be taken from trees of three different size classes, at different distances from a ditch and from all four Operational Groups. If a drainage response is observed, a small destructive sample should be collected to examine further where the additional wood fiber is being allocated in the tree's bole.

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